SOME ASPECTS OF INTERSPECIFIC RELATIONSHIPS INVOLVING

NORTHERN PINK SHRIMP, *PANDALUS BOREALIS*, KRØYER,

IN FOUR BAYS OF KODIAK ISLAND

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SOME ASPECTS OF INTERSPECIFIC RELATIONSHIPS INVOLVING NORTHERN PINK SHRIMP, *PANDALUS BOREALIS*, KRØYER, IN FOUR BAYS OF KODIAK ISLAND

A

THESIS

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By

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ABSTRACT

Interspecific relationships involving northern pink shrimp, *Pandalus borealis* Krøyer, were analyzed using catch data collected in Ugak, Kiliuda, Two-Headed and Alitak Bays, of Kodiak Island, from 1976 to 1978. Analytical methods included occurrence ranking, and testing of associations and relationships. Similar temporal and spatial boundaries were shared by 10 shrimp and 51 fish species. Northern pink shrimp were related to the predators: arrowtooth flounder, flathead sole, Pacific halibut, yellowfin sole, Pacific cod and walleye pollock, and the non-predatory capelin and Pacific sandfish. Relationships varied with species, year, season and bay. A formula is proposed for evaluating predation pressure. Estimated predator biomass was 1,569 kg/km^2 in 1976, 1,289 kg/km^2 in 1977 and 2,048 kg/km^2 in 1978. Predation pressure increased from 1976 to 1977 and decreased in 1978. Water temperature was assumed to increase from 1976 to 1978. No apparent relationship was found between water temperature variation and change in species relationships.

PREFACE

In Elements of Mathematical Biology (Lotka 1956), W. A. Herdman is quoted as saying:

> Aquaculture is as susceptible to scientific treatment as agriculture; and the fisherman who have been in the past too much the hunter if not the devasting raider, must become the future, the settled farmer of the sea, if the harvest is to be less precarious.

This statement appears as a condemnation of fishermen and their practices, and in 1923, when this statement was made, may have been applicable. Fishermen are hunters, searching out their quarry; and only in limited instances, sowing the seeds of future crops. In my experiences with fishermen I have found them to contradict this implication. They speak of the necessity of protecting marine resources, not only for their interest, but also the integrity of the resource. The key to protection is the cooperative effort of fishermen and regulatory agencies based on as broad a knowledge of the resource and its environment as possible.

This thesis is my attempt to look at one aspect of the northern pink shrimp environment and its effect upon this marine resource. It is not an attempt to predict populations at present or in the future but rather to investigate an area of interest to me and hopefully of importance in the shrimp fishery. I intend to look at species relationships and how changes in relationships affect a marine resource. Predation is natural and manmade, and I feel that man must better understand natural predation before he can properly modify the impact of his predation.

Observers will read this work, realize that very little field activity was involved and criticize the concept of a reference-based thesis. I do not feel my decision requires a defense, but an explanation will be given. Data collections are made with respect to a specific hypothesis. Often however, the data are useful in areas not addressed by the original hypothesis. The Alaska Department of Fish and Game collects catch data on northern pink shrimp primarily to estimate population sizes and to estabish harvest limits. I felt that this data base would supply a better temporal-spatial framework for the analysis of species relationships than I could practically provide. It is obvious that the use of pre-existing data, where applicable, saves money and time as well as fostering scientific cooperation.

In the years between undergraduate and graduate school, I worked with the public attempting to resolve environmental problems without environmental destruction. I enjoyed the opportunity of helping and protecting, and wish to carry on in this manner. I expect in the future that these types of data will serve as the basis of my work and provide the foundation of advice and recommendations.

ACKNOWLEDGEMENTS

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INTRODUCTION

Pandalid shrimp have been commercially exploited in the waters of the Gulf of Alaska since 1915 (Barr 1970a). From 1959 to 1972, the bays of Kodiak Island (Fig. 1) were the most productive areas in the Alaskan shrimp fishery. As a decline in the commercial shrimp catches became apparent in 1975, interest grew concerning the biotic and abiotic factors affecting this fishery.

The most important shrimp species in the Alaskan fishery is northern pink shrimp, *Pandalus borealis* Krøyer, which makes up 60-90% of the total shrimp fishery. All pandalid shrimp are protandric hermaphrodites (Rasmussen 1947) maturing and functioning as a male prior to transition to a female. Northern pink shrimp have a circumpolar distribution in the Atlantic and Pacific Oceans. Fishable concentrations are generally found over smooth muddy or sandy bottoms at depths of 60-400 m, although individuals have been taken at depths of 1400 m. This species is found at water temperatures ranging from -1 to 11°C (Butler 1971). Northern pink shrimp spawn in the fall after the female moults to a specialized breeding dress (McCrary 1971). Time of the spawn is apparently related to water temperature (Butler 1971; Dow 1979) as is the ovigerous (egg development) period. Males mature in approximately 1.5 years in Alaskan waters and transition begins 2 to 2.5 years later. Northern pink shrimp are approximately 4 to 5 years old when they enter the fishery, at which time mature females may have grown to 17 cm in length and weigh 12 g. Beam or otter trawls are used to catch these shrimp.

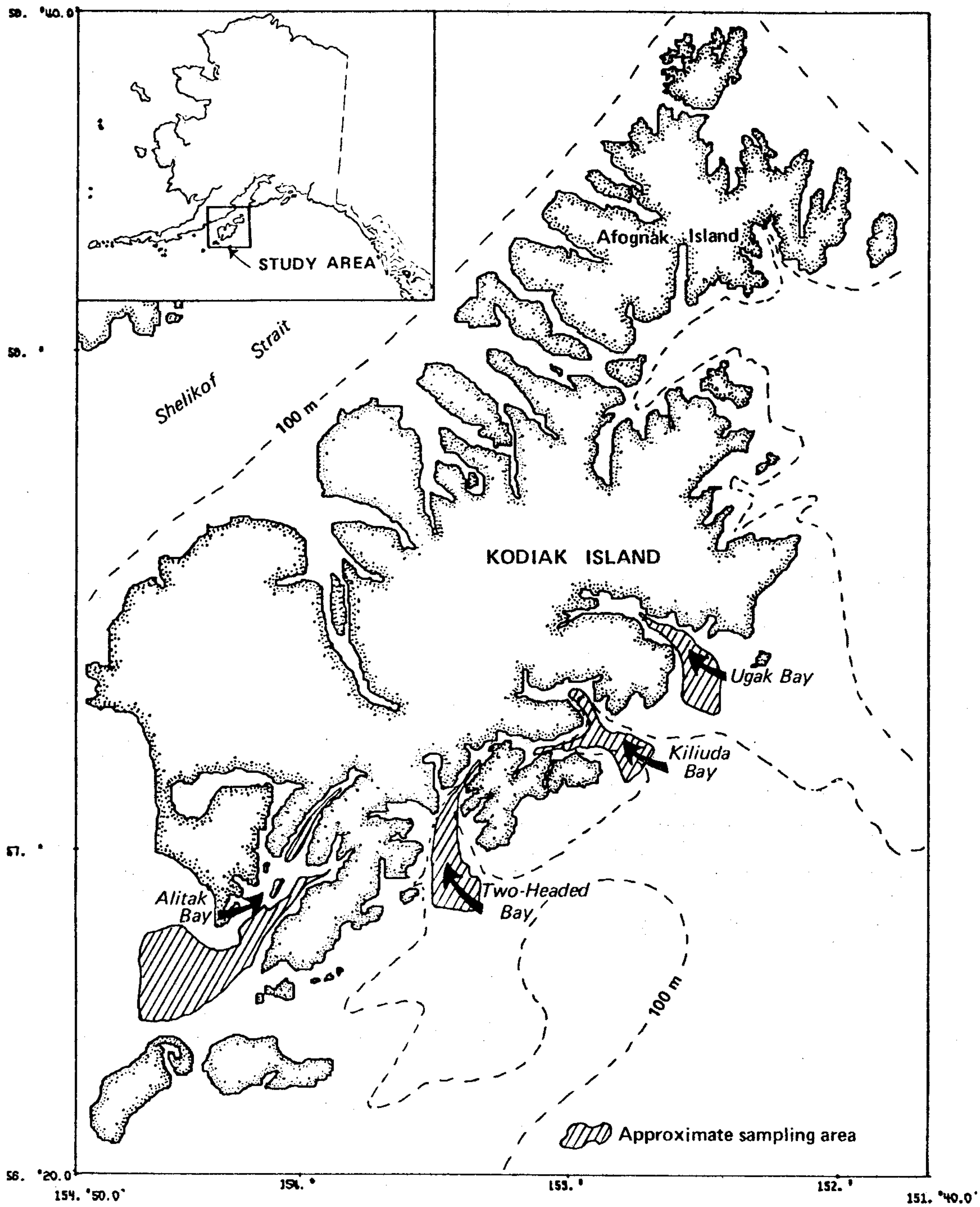

Figure 1. Study area of Kodiak Island, Alaska.

Previous research has focused on the biology and distribution of northern pink shrimp populations (Allen 1959; Butler 1964) and the economic value of this fishery (Barr 1970a). Feeding studies show the importance of pink shrimp to various predators in the Gulf of Alaska (Jewett unpublished data; Rogers *et al.* 1979) and the Bering Sea (Mito 1974). Benthic surveys conducted in these areas document the importance of this species in the epibenthic community (Jewett and Feder 1976; Feder and Jewett 1977).

Incidental catch species are those species not targeted by the fishery. Increased incidental (non-pandalid) catch in relation to water temperature was discussed in a study of the Gulf of Maine (Dow 1975). It was noted that during years of relatively high water temperature, species normally restricted to areas south of the Gulf of Maine were taken in commercially important numbers. Increases involved not only total biomass but also number of species. Conversely during years of low water temperature the abundance of these species in the Gulf of Maine declined.

Results of a shrimp survey cruise in December, 1977 showed high percentages of incidental species in the bays of Kodiak Island. Incidental species included Pacific cod and walleye pollock. These findings stimulated the formulation of the hypothesis that a change in predator-prey relationships within the northern pink shrimp community had taken place and that these changes resulted in changes in predation pressure.

Coincidental with the increase in incidental catch, was a warming trend in the waters of the Gulf of Alaska. A corollary of the above hypothesis is that variation in predator-prey relationships were a result of increased water temperature.

This thesis describes interspecific relationships involving northern pink shrimp, using catch data collected in the bays of Kodiak Island. The analytical methods used were occurrence ranking and testing of association and interspecific relationships. Significant similarity in biomass variation of associated species were indicators of interspecific relationships.

MATERIALS AND METHODS

1. Data Sources

Catch data on northern pink shrimp and incidental catch species were supplied from the Alaska Department of Fish and Game (ADF&G) and the National Marine Fisheries Service (NMFS). Incidental catch data included name and weight of pandalid, non-pandalid shrimp species and other invertebrates, and fish species.

Data supplied by the ADF&G were collected from 1970 to 1978 primarily during May through September and in October and December. The NMFS data were collected throughout the year during the period from 1948 to 1978. The areas observed were four bays of Kodiak Island: Ugak, Kiliuda, Two-Headed, and Alitak Bays (Fig. 1). These bays have been the locations of high concentrations of northern pink shrimp and have been sampled more intensively than the other bays of this island.

Catch data were separated into the reproductive and growth seasons of northern pink shrimp. The reproductive season was determined to run from October to March, corresponding to the period of egg extrusion and egg bearing. The remainder of the year was designated as the growth period. (Approximately 90% of the ADF&G data were collected from May through September or in October and December).

2. Sampling Methods

The ADF&G shrimp survey cruises in these areas were conducted aboard the M/V *Resolution*, an 80 ft stern trawler. Collections were made over a 30-min period for one nautical mile, at a speed of 2 kn. A number of trawls were made to delineate shrimp populations at the mouths of bays. Occupation of the remaining stations was based on a schedule derived from a computer generated random number table. A high opening, 18.6 m footrope trawl net, designed to fish approximately 50 cm from the bottom, was used for data collection. This may bias the catch toward bottom dwelling species. The apparent bias is considered acceptable as this study is concerned with relationships involving bottom dwelling northern pink shrimp and co-occurring fish species. All trawls are bottom trawls and were conducted during daytime. Upon retrival, the total catch weight was measured on board. Large incidental catch species were counted, and weights estimated.

A sample of the catch was taken and weighed. The fish species in this sample were separated by species and weighed. The percentage by weight of species in this sample was representative of the composition of the total catch. After the shrimp weight for the total catch was determined, a 5 lb subsample of shrimp was taken for each 500 lb of total catch.

The subsample of shrimp was identified by species and each species portion weighed. Shrimp species collected included northern pink shrimp, *P. borealis*; humpy shrimp, *P. goniurus*; coonstripe shrimp, *P. hypsinotus*; sidestripe shrimp, *P. dispar* and crangonid species. Northern pink shrimp were then separated by sex.

3. Standarization of Biomass Data

An area swept method was used to calculate biomass per unit area (Ricker 1958). The horizontal mouth opening of the trawl net was multiplied by the distance trawled in meters. Species wet weight in kilograms was divided by this area giving a value in kg/m^2.

4. Analytical Methods

The analytical methods utilized in this study were: (1) occurrence ranking, (2) determination and testing of species association, and (3) analysis of variance and biomass regression.

Pielou (1976) states,

> If two co-occurring species are affected by the same environmental factors, or if they have some effect, either favorable or unfavorable, on each other, their patterns will not be independent; the species will be associated, either positively or negatively.

Associations were however, based upon occurrence or lack of ocurrence with no regard for species biomass. The observation of a fish species in one or more bays was assigned the same value regardless of of biomass. The incorporation of species biomass into the analysis provided an indication of shifts in the biomass of associated species. This thesis assumed that if shifts in the biomass of associated species were found to be significantly similar there existed a relationship between these species. Variations in biomass of associated species were an indication of distributional changes due to species relationships.

4.1 Occurrence Ranking

Ranking of the species observed in each bay was done by determining the frequency of occurrence of a species during the sampling period. Ranking is not suitable for determining species associations (Krebs 1972), so this method was used to compare the occurrence of species in the respective bays. The resulting percentages were ranked for each bay and the species ranking in the top ten for each bay were selected for further consideration.

4.2 Test of Association

The association between a given species and northern pink shrimp was calculated and the significance tested (Hurlbert 1969; Pielou 1976). This determination of association was based upon occurrence only, disregarding specific biomass. Northern pink shrimp and a species in the top ten of the rank listing were selected for association testing. The frequencies were arranged in a 2 X 2 contingency table as follows:

		SPECIES 2		
		PRESENT	ABSENT	
SPECIES 1	PRESENT	A	B	M = A+B
	ABSENT	C	D	L = C+D
		R = A+C	S = B+D	N = R+S = M+L

where N is the total number of stations, A the number of stations containing northern pink shrimp and the selected species, B the number of stations containing northern pink shrimp and not the selected species, C the number of stations containing the selected species and not northern pink shrimp, and D the number of stations containing neither species.

The probability of the observed frequencies was calculated and the corrected chi-squared values were derived from the following equation:

$$\chi^2_{corr} = \frac{(|AD-BC|-N/2)^2 \times N}{L \times M \times R \times S} \quad (\text{d.f.} = 1)$$

Corrected chi-squared values were calculated for the species ranking in the top ten by frequency of occurrence. Species were associated with northern pink shrimp if probability of a greater chi-square value was less than or equal to 0.10 ($\rho \leqq .10$). The pattern of presence and absence of associated species within a bay was considered random 10% of the time.

4.3 Analysis of Variance and Biomass Regression

In contrast to occurrence ranking and testing of association, this method of determining interspecific relationships utilized biomass. The strength of the relationship was based on the correlation coefficient derived from the biomass regression. Changes in species biomass within a community reflected variations in the structure of that community.

Three schemes were utilized in the regression of the biomass data. First, the data for the four bays were lumped together for the entire three-year period and for individual years, ignoring any seasonal variation. A second series of regressions, of total and yearly data, was done after the data were separated into reproductive and growth seasons. A final regression series was done on total and yearly data from the individual bays.

An one-way analysis of variance was performed and the resulting *F* values used to test the hypothesis that a relationship existed between two species. The *F* value was considered significant if the *P* value, the probability of a greater *F* value, was 0.10 (10%) or less. A significant *F* value rejected the null hypothesis and indicated a relationship between species. A correlation coefficient was calculated for each relationship by the regression of the respective species biomass; the biomass of the selected fish species was regressed against the biomass of northern pink shrimp. The magnitude of the correlation coefficient was used to compare the strengths of relationships of northern pink shrimp and different fish species. A positive coefficient indicated a similarity of response of one population to changes of the related population. Such a response may be an increase or decrease in the sizes of the populations. A negative coefficient reflected an increase in one population and a coincident decrease in the other. The cause of these changes may be linked to predation or competition. To state only that the effect of the relationship is positive or negative (Krebs 1972) or favorable or unfavorable (Pielou 1976) is unsatisfactory.

5. Estimation of Predation Pressure

Estimations of predation pressure required knowledge of predator biomass, feeding or digestive rates and the importance of the prey species in the diet of the predator (Bajkov 1935). Predator biomass per unit area was determined from stations at which predators occurred with northern pink shrimp. It was assumed that overall feeding rate was 1.5% of body weight per day (Daan 1973) as data on feeding rate was lacking. Percent weight of the prey species in the gut contents of the predator was used as an indicator of prey importance. These data were available for arrowtooth flounder, flathead sole, yellowfin sole, Pacific cod and walleye pollock, but were lacking for Pacific halibut.

Prey biomass removed was estimated with the following equation:

$$P = \sum_i B_i \times F_i \times I_i$$

where P = predation

B = biomass of the i^{th} predator,

F = feeding rate of the i^{th} predator,

and I = dietary importance of prey.

Predation was expressed in kilograms per square kilometer per day ($kg/km^2 \cdot day$) and total catch from the respective bays was converted to these units for comparison. Comparisons were made using commercial catch data from areas which were actively fished. In 1976-77 and 1977-78, this included Kiliuda, Two-Headed and Alitak Bays, and in 1978-79 Two-Headed and Alitak Bays.

6. Water Temperature Data

Mean monthly sea surface temperatures were obtained from NOAA/NMFS for the period 1962 to 1978. Sea surface temperature measurements were made on a ship of opportunity basis. Observations were made in a 300 km^2 area centered at 58°N latitude and 150°W longitude off the coast of Kodiak Island, in the Gulf of Alaska. The measurements were compiled every 12 hr, linearly weighted and averaged over a month.

Long term water temperature data were not available for the study area so sea surface temperatures were used as indicators of bottom temperature variations. As depth increases, the range of annual temperature variation decreases, and the time of occurrence of temperature maxima and minima are delayed with depth (Neumann and Pierson 1966). Available surface and bottom water temperature from the four bays addressed (ADF&G unpublished data; NMFS unpublished data) were compared with the mean sea surface from the Gulf of Alaska. If seasonal variations were similar, it was assumed that overall temperature trends were also the same.

7. Limitations of Analysis

Analyses of species relationships in the community associated with northern pink shrimp require discussion of the nature and structure of the data provided. The reports of collections made during NMFS cruises were limited in scope due to the recording procedure utilized. By listing the four most prominent species by weight, many other species were not documentated. The NMFS data alone indicated a depauperate condition in these bays. Therefore, the NMFS data were not used as a primary data base for analyses but rather as a comparison for observations made from the ADF&G data.

8. Data Quality

The data provided by the ADF&G were collected during survey cruises conducted in the waters of Kodiak Island since 1970. Reports of incidental catch were not made until the end of 1974. Additionally, until 1976, the shrimp catch was not separated by species. This restricted the usable data base for this study to the years 1976, 1977 and 1978.

A total of 80 species were listed in the ADF&G and the NMFS data. The NMFS data listed species by name and the ADF&G reports utilized numeric codes for species cataloging. In comparison with the NMFS standard species code listing, it was found that 19 of the species codes in the ADF&G reports were not found in the standard species listing. Two sources of error were possible: (1) while transferring the data into the computer typographical errors were made; and (2) errors were present in the data as provided.

As the unlisted species codes were compiled for each station, the questioned codes were checked and transcription errors corrected. It was found that in most cases the transferral of the code was correct but that the code, in the reports, was in error. Although these errors affected the results of the analysis of species relationships, it was felt that the effect was minimal and would not significantly alter results.

RESULTS

1. Some Physical Aspects of the Bays

Occupied stations were located within the principal shrimp fishing areas of Ugak, Kiliuda, Two-Headed and Alitak Bays. The fishing areas range in size from approximately 72 km^2 in Ugak Bay to 333 km^2 in Alitak Bay (Table 1). Mean station depth ranged from 91 to 154 m. The bottom contours and configuration of the principal shrimp fishing grounds are such that most areas within the 90-200 m depth range are parts of gullies. The sediment within these areas is primarily green or grey mud (McCrary and Peterson 1971).

The major currents of the Gulf of Alaska are characterized by counter-clockwise flow along the southern coast of Alaska (Fig. 2). Drift bottle recoveries (Dodimead and Hollister 1962) indicate that the current splits around Kodiak Island and there is movement of stream waters into bays. A central trough located in Kiliuda and Two-Headed Bays is continuous with the off-shelf Alaska Stream at depths of greater than 100 m.

Sea surface temperatures measured off the coast of Kodiak Island show the expected seasonal fluctuations; warming to a mid-summer maximum and cooling to a minimum in late winter. Sea surface temperature in the Gulf of Alaska and surface and bottom temperatures within the bays showed similar seasonal variations (Fig. 3). Surface and bottom water temperatures

Table 1. Some physical aspects of Ugak, Kiliuda, Two-Headed and Alitak Bays, Kodiak Island.

Item	Bay: Ugak	Kiliuda	Two-Headed	Alitak
Area (km^2)	72.3	125.1	190.4	333.1
Depth (m)				
Range	86-104	80-177	40-176	101-188
Mean	100	154	91	134
Sediment Type	Green-Grey mud	Green-Grey mud	Green-Grey mud	Green-Grey mud
Water Temperature (°C)				
Surface				
Aug-Sept*	10.8-11.2	10.7-12.0	11.2	11.0-12.4
Dec-March**	2.8-5.7	3.3-3.5	2.8-4.8	2.2-6.1
Bottom				
Aug-Sept*	7.7-8.1	4.8-7.9	6.3	2.8-9.6
Dec-March*	2.8-6.0	3.4-5.9	3.7-6.0	2.6-5.6
May-July**	4.7	4.5-4.9		2.0-3.9

* Alaska Department of Fish and Game, 1978-80 (unpublished data)
**National Marine Fisheries Service, 1971-74 (unpublished data)

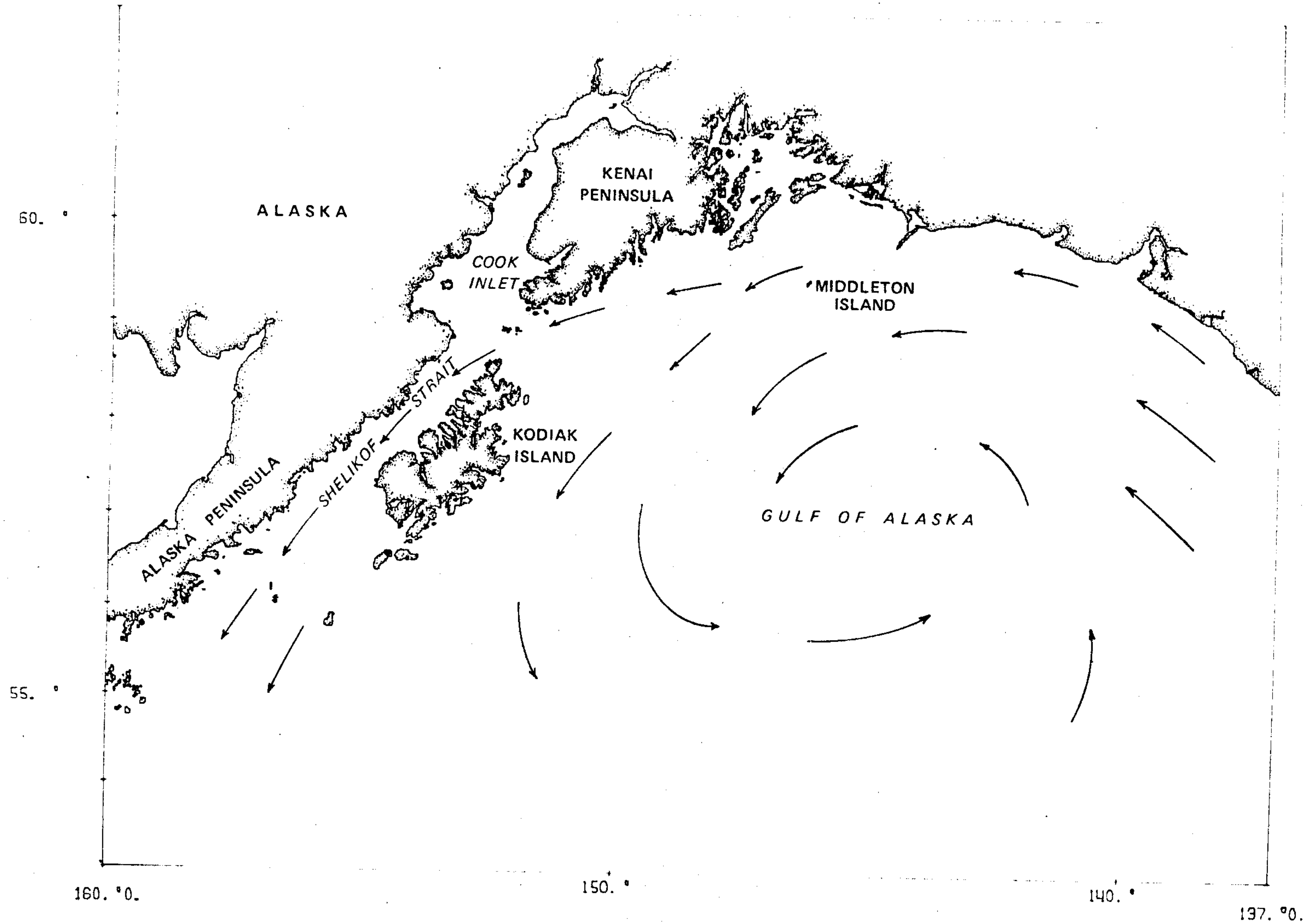

Figure 2. Surface current pattern in the Gulf of Alaska (from Brower *et al.* 1977).

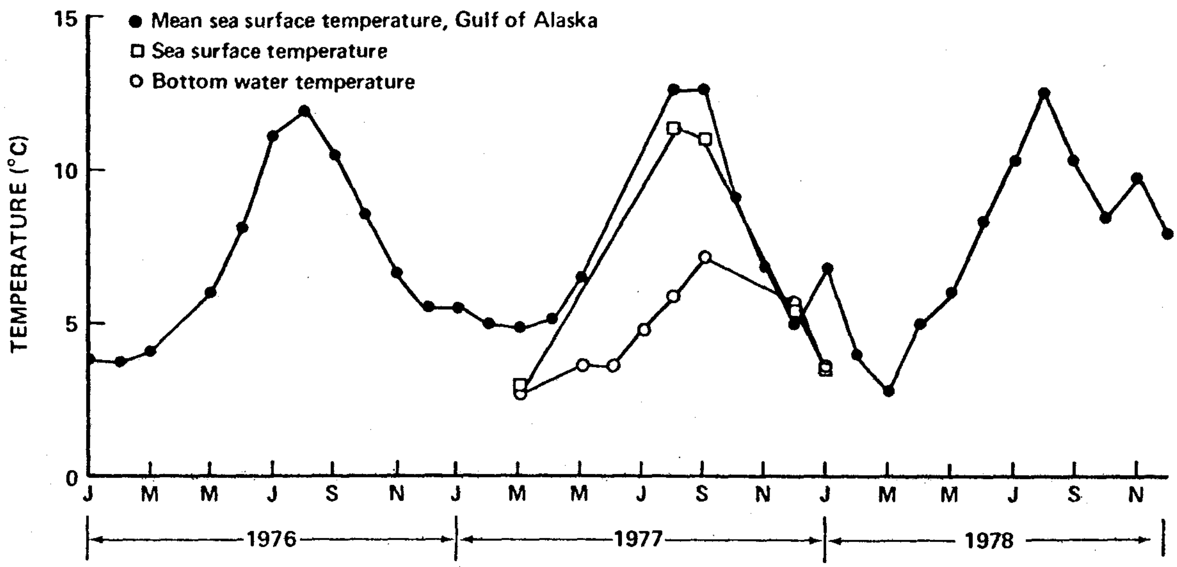

Figure 3. Mean sea surface temperature from the Gulf of Alaska (58°N Lat., 150°W Long.), and sea surface and bottom water temperatures from Ugak, Kiliuda, Two-Headed and Alitak Bays.

measured during the reproductive period (October-March) were lower than those observed during the growth period (April-September).

Deviations from the monthly mean of the sea surface data from 1962-78 (Fig. 4) indicate a recent warming in this area of the Gulf of Alaska. It was assumed that a similar warming trend has occurred in the area of study.

2. Commercial Catch

Table 2 shows the commercial shrimp catch for the Kodiak Island District for 1960-61 to 1978-79. Excluding declines due to the 1964 earthquake, commercial catch in the Kodiak Island shrimp fishery increased from 2.1 x 10^3 t in 1960-61 to 34.1 x 10^3 t in 1971-72. An initial decline, observed in 1973, was due to the imposition of harvest limtis. Commercial catch has declined since 1974 and by 1979 amounted to 27% of the 1972 catch of 34.1 x 10^3 t.

Ugak Bay was closed from 1973 through 1978 to all but minimal commercial exploitation. In 1976, 1977 and 1979 no commercial catch was recorded for Ugak Bay. Catches in 1973, 1975 and 1978 ranged from 10 to 28 t. Commercial catch in Kiliuda Bay increased in 1975 and decreased in 1976 (Fig. 5). Catches remained stable through 1978 and dropped in 1979. Catches in Two-Headed Bay remained stable from 1974 through 1977 (Fig. 5). In 1978, a 64% decline was observed followed by a further decline in 1979. Commercial catch in Alitak Bay declined 54% from 1974 to 1975 and then stabilized at approximately 2 x 10^3 t (Fig. 5). This catch level was maintained through 1979. The Ugak Bay shrimp fishery

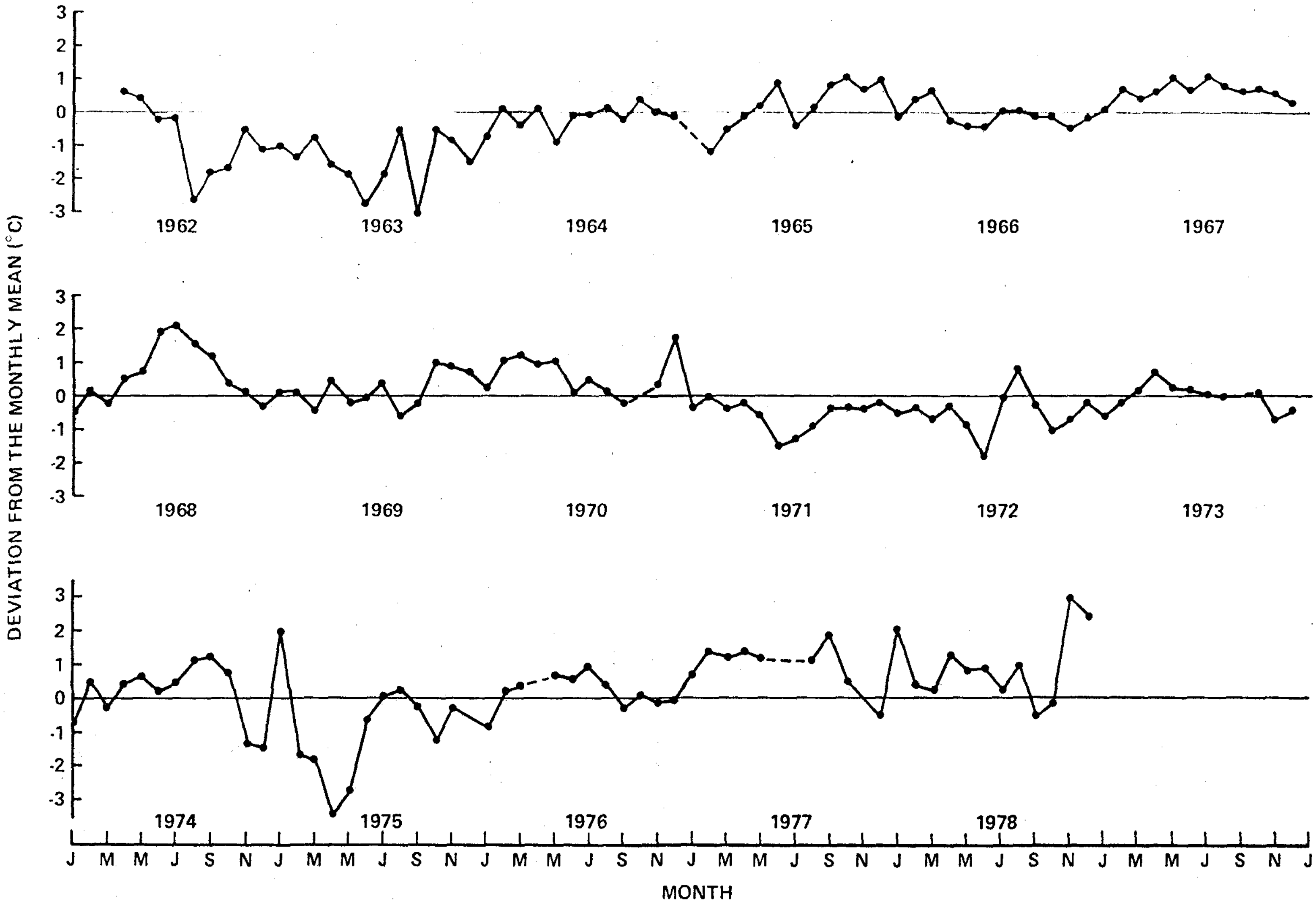

Figure 4. Deviations from the mean monthly sea surface temperature in the Gulf of Alaska (58°N Lat., 150°W Long.).

Table 2. Seasonal shrimp catches in the Kodiak District, 1960-79 (Jackson 1979)

Season	Harvest (t)
1960-61	2.1
1961-62	5.3
1962-63	5.4
1963-64	3.6
1964-65	2.4
1965-66	7.4
1966-67	12.7
1967-68	15.6
1968-69	17.2
1969-70	20.3
1970-71	29.6
1971-72	34.1
1972-73	29.6
1973-74	25.5
1974-75	26.4
1975-76	22.3
1976-77	21.2
1977-78	12.0
1978-79	9.3

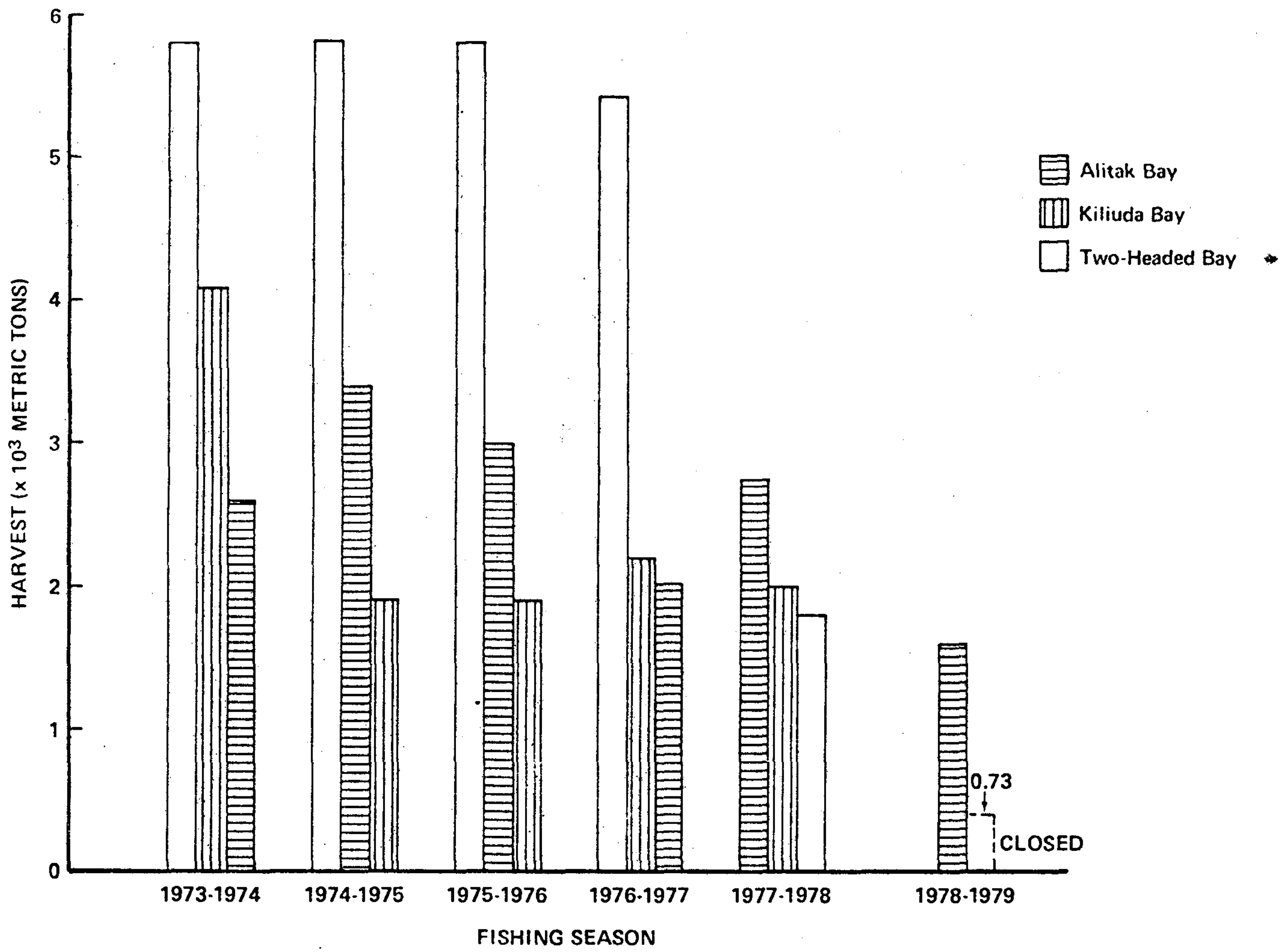

Figure 5. Commercial shrimp catch in Kiliuda, Two-Headed and Alitak Bays for the fishing seasons 1973-1974 through 1978-1979.

collapsed in 1973. Commercial catch in Kiliuda Bay declined in 1976 and remained at approximately the same level until this bay was closed prior to the 1978-1979 season. The shrimp fishery of Two-Headed Bay was stable until collapsing in 1977. The catch levels of Alitak Bay remained stable after a decline of 50% in 1975.

3. Species Occurring with Pink Shrimp

The species observed in the study area are listed in Table 3. The species included 10 shrimp species, 13 species of the order Pleuronectiformes (flatfish) and 38 other species of the class Osteichthyes. The shrimp included 5 pandalid species, and species of crangonid and hippolytid shrimp. Northern pink shrimp were observed to be the most common throughout the study area.

Fish of the order Pleuronectiformes include shrimp predators such as flathead sole, arrowtooth flounder, Pacific halibut and yellowfin sole. The remaining members of the class Osteichthyes were referred to as roundfish. These species include benthic dwellers, such as sculpins and lumpfishes, and pelagic species including capelin, herring and eulachon. Also observed were Pacific cod, walleye pollock and Pacific tomcod which seek prey in the benthic and pelagic regions.

4. Occurrence Ranking

4.1 Ugak Bay, 1976-78

From 1976 to 1978, 45 stations were occupied in Ugak Bay; 21 in 1976, 11 in 1977 and 13 in 1978. Thirty-three species including 6 shrimp, 8

Table 3. Shrimp and fish species observed in study area, 1976-78.

Common Name	Scientific Name
Shrimp	
Northern pink shrimp	*Pandalus borealis* Krøyer
Spot shrimp	*Pandalus platyceros* Brandt
Humpy shrimp	*Pandalus goniurus* Stimpson
Coonstripe shrimp	*Pandalus hypsinotus* Brandt
Sidestripe shrimp	*Pandalopsis dispar* Rathburn
Crangonid shrimp	*Argis* spp.
Hippolytidae	*Spirontocaris* sp.
Hippolytid	*Eualus* sp.
Hippolytid	*Eualus* sp.
Unidentified shrimp	Pandalidae spp.
Fish	
Arrowtooth flounder	*Atheresthes stomias* (Jordan and Gilbert)
Rex sole	*Glyptocephalus zachirus* Lockington
Flathead sole	*Hippoglossoides elassodon* Jordan and Gilbert
Pacific halibut	*Hyppoglossus stenolepsis* Schmidt
Butter sole	*Isopsetta isolepsis* (Lockington)
Rock sole	*Lepidopsetta bilineata* (Ayres)
Yellow sole	*Limanda aspera* (Pallas)
Dover sole	*Microstomus pacificus* (Lockington)
English sole	*Parophrys vetulus* Girard
Starry flounder	*Platichthys stellatus* (Pallas)
Sand sole	*Psettichthys melanostictus* Girard
Greenland turbot	*Reinharditius hipploglossoides* (Walbaum)
Unidentified flat fish	
Pacific herring	*Clupea harengus pallasi* Valenciennes
Chinook salmon	*Oncorhynchus tshawytscha* (Walbaum)
Smelt	Osmeridae
Rainbow smelt	*Osmerus mordax dentax* (Steindachner)
Capelin	*Mallotus villosus* (Müller)
Eulachon	*Thaleichthys pacificus* (Richardson)
Pacific tomcod	*Microgadus proximus* (Girard)
Pacific cod	*Gadus macrocephalus* Tilesius
Walleye pollock	*Theragra chalcogramma* (Pallas)
Pacific sandfish	*Trichodon trichodon* (Tilesius)
Sable fish	*Anoplopoma fimbria* (Pallas)
Greenling	Hexagrammidae
Kelp greenling	*Hexagrammus decagrammus* (Pallas)
Northern ronquil	*Ronquilus jordani* (Gilbert)
Searcher	*Bathymaster signatus* Cope

Table 3. Continued.

Common Name	Scientific Name
Sculpin	Cottidae
Brown Irish lord	*Hemilepidotus spinosus* (Ayres)
Red Irish lord	*H. hemilepidotus* (Tilesius)
Yellow Irish lord	*H. jordani* Bean
Sculpin	*Myxocephalus* sp.
Great sculpin	*M. polyacanthocephalus* (Pallas)
Spineyhead sculpin	*Dasycottus setiger* Bean
Sturgeon poacher	*Agonus acipenserinus* Tilesius
Lumpsucker	Cyclopteridae
Snailfish	Cyclopteridae
Marbled snailfish	*Liparis dennyi* Jordan and Sparks
Smooth lumpsucker	*Aptocyclus ventricosus* (Pallas)
Snake prickleback	*Lumpenus sagitta* Willimovsky
Longsnout prickleback	*Lumpenella longirostris* (Everman and Goldborough)
Black rockfish	*Sebastes melanops* Girard
Dusky rockfish	*S. ciliatus* Girard
Yellowtail rockfish	*S. flavidus* (Ayres)
Pacific Ocean perch	*S. alutus* (Gilbert)
Eelpout	Zoarcidae
Shortfinned eelpout	*Lycodes brevipes* Bean
Wattled eelpout	*L. palearis* Gilbert
Blenny	Blennidae

flatfish and 19 roundfish species were found. The top ten ranked species included 4 shrimp, 3 flatfish and 3 roundfish species (Table 4). Northern pink shrimp were observed at 32 (71%) stations. Other shrimp observed were the sidestripe (36%), the humpy (33%) and the coonstripe shrimp (22%). The most common fish were flathead sole (69%). Also observed were yellowfin sole (62%), Pacific sandfish (60%) and walleye pollock (51%). Lower ranking fish species included capelin (47%) and Pacific halibut (18%).

4.2 Kiliuda Bay, 1976-78

A total of 157 stations were occupied in Kiliuda Bay; 72 in 1976, 33 in 1977 and 52 in 1978. The 40 species observed included 6 shrimp species, 7 flatfish and 27 roundfish species. The top ten species ranks included 3 shrimp, 4 flatfish and 3 roundfish (Table 4). The most commonly occurring species was flathead sole (69%). Also common were walleye pollock (67%). Northern pink shrimp were observed at 99 (63%) stations, which was the lowest percentage of occurrence of this species. Sidestripe (31%) and coonstripe shrimp (20%) were ranked in the top ten. Additional and common were arrowtooth flounder (40%), capelin (34%) and Pacific cod (24%). Other flatfish yellowfin sole (21%) and Pacific halibut (18%) were lower ranked.

4.3 Two-Headed Bay, 1976-78

During the occupation of 89 stations in Two-Headed Bay; 33 in 1976, 33 in 1977 and 23 in 1978, 41 species were observed; 6 shrimp, 7 flatfish

Table 4. Rank of species occurrence for the years 1976-78. N is number of stations in each bay.

Bay	Species	Occurrence	Percent
Ugak Bay	Northern pink shrimp	32	71
N = 45	Flathead sole	31	69
	Yellowfin sole	28	62
	Pacific sandfish	27	60
	Walleye pollock	23	51
	Capelin	21	47
	Sidestripe shrimp	16	36
	Humpy shrimp	15	33
	Coonstripe shrimp	10	22
	Pacific halibut	8	18
Kiliuda Bay	Flathead sole	109	69
N = 157	Walleye pollock	105	67
	Northern pink shrimp	99	63
	Arrowtooth flounder	63	40
	Capelin	53	34
	Sidestripe shrimp	50	31
	Pacific cod	37	24
	Yellowfin sole	33	21
	Coonstripe shrimp	30	20
	Pacific halibut	28	18
Two-Headed Bay	Northern pink shrimp	84	94
N = 89	Flathead sole	67	75
	Walleye pollock	55	62
	Arrowtooth flounder	50	56
	Brown Irish lord	39	43
	Sidestripe shrimp	35	39
	Yellowfin sole	24	27
	Pacific cod	22	25
	Capelin	21	24
	Pacific halibut	15	17
Alitak Bay	Northern pink shrimp	44	80
N = 55	Humpy shrimp	40	73
	Coonstripe shrimp	39	71
	Flathead sole	39	71
	Yellowfin sole	27	49
	Pacific herring	24	44
	Walleye pollock	23	42
	Capelin	20	36
	Sidestripe shrimp	17	31
	Crangon	15	27

and 28 roundfish species. Included in the top ten species ranks were 2 shrimp, 4 flatfish 4 roundfish (Table 4). Northern pink shrimp was the most common species, occurring at 84 (94%) stations. This was the highest percentage of occurrence of this shrimp among the four bays. The most frequently occurring fish species was flathead sole (75%). Also common were arrowtooth flounder (56%) and yellowfin sole (27%). The most common roundfish was walleye pollock (62%). Additional and common roundfish were brown Irish lord (43%), Pacific cod (25%) and capelin (24%).

4.4 Alitak Bay, 1976-78

A total of 55 stations were occupied in Alitak Bay; 11 in 1976, 23 in 1977 and 21 in 1978. The thrity-three species observed consisted of 6 shrimp, 6 flatfish and 21 roundfish. The top ten species ranks included 5 shrimp, 2 flatfish and 3 roundfish (Table 4). Northern pink shrimp were found at 44 (80%) stations. Additional and common were humpy (73%) and coonstripe shrimp (71%). Sidestripe (39%) and crangonid shrimp (27%) were observed less frequently. Flathead sole was the most frequently occurring fish species (71%). Additional and common was yellowfin sole (49%). The most commonly occurring roundfish were Pacific herring (44%), walleye pollock (42%) and capelin (36%).

4.5 Combined Data for Four Bays, 1976-78

A total of 346 stations were occupied during the study period, 137 in 1976, 100 in 1977 and 109 in 1978. Northern pink shrimp were observed at 259 (75%). Commonly occurring shrimp included humpy, coonstripe, sidestripe and *Crangon* spp. The most observed flatfish were flathead sole (70%). Additional common flatfish included yellowfin sole, arrowtooth flounder, and Pacific halibut. Walleye pollock was the most numerous roundfish species (59%). Capelin, Pacific sandfish and Pacific cod, also occurred frequently.

It is noteworthy that northern pink shrimp, flathead sole and walleye pollock were consistently ranked high in all bays. Alitak Bay differed from the other bays in that shrimp occupied the first three ranks while in the other bays, only northern pink shrimp ranked in the top five. There was no pattern in the ranking of flatfish and roundfish from bay to bay nor was there any similarity in the number of species occurring in each bay.

5. Test of Association

The test of association was based upon the pattern of presence and absence of two species within the sampling area. The significance level of the calculated chi-square value was a measure of the probability of encountering these species in similar situations of presence and absence. The results show that high ranking species were not always associated with northern pink shrimp. Similarly, two species which showed the same ranking were not always associated with northern pink shrimp. Table 5 shows the results of the test of association of northern pink shrimp and co-occurring species.

Table 5. χ^2 values for fish species ranking in the top ten species ranks for each bay. A significant χ^2 value indicates an association between northern pink shrimp and respective species.

Species	Bay			
	Ugak	Kiliuda	Two-Headed	Alitak
Arrowtooth founder	1.04	25.03*	0.08	0.03
Flathead sole	6.02*	4.02*	0.08	0.93
Pacific halibut	0.49	1.51	0.18	6.88*
Yellowfin sole	5.92*	1.21	0.02	2.00
Pacific cod	0.57	3.54*	1.26	0.34
Walleye pollock	7.44*	0.44	6.02*	2.78*
Pacific sandfish	2.62*	9.97*	0.03	1.40
Capelin	13.47*	39.97*	0.77	6.02*
Pacific herring	0.22	0.54	0.03	0.23
Brown Irish lord	0.18	1.34	1.56	0.08

*χ^2 significant at $p \leqq 0.10$

5.1 Ugak Bay

Five species were found significantly associated with northern pink shrimp in Ugak Bay. These species were flathead sole, yellowfin sole, walleye pollock, Pacific sandfish and capelin.

5.2 Kiliuda Bay

Similar to Ugak Bay, 5 species were found significantly associated with northern pink shrimp in this bay. The species were flathead sole, arrowtooth flounder, Pacific cod, capelin and Pacific sandfish.

5.3 Two-Headed Bay

Walleye pollock was the only fish species significantly associated with northern pink shrimp in Two-Headed Bay. Flathead sole were observed more frequently than walleye pollock in this bay but were not found significantly associated with northern pink shrimp.

5.4 Alitak Bay

Pacific halibut, walleye pollock and capelin were associated with northern pink shrimp in this bay. Alitak Bay was the only bay in which northern pink shrimp and Pacific halibut were found associated.

5.5 Combined Data for Four Bays

Fourteen fish species, occurring in the top ten ranks of all the stations, were tested for association with northern pink shrimp. These species included 4 flatfish species and 10 roundfish species. Flathead sole, yellowfin sole, arrowtooth flounder and Pacific halibut showed significant association with northern pink shrimp. Also associated with this shrimp were walleye pollock, Pacific cod, capelin and Pacific sandfish. The remaining fish species were not significantly associated with northern pink shrimp.

There was no similarity in the frequency of occurrence, the number of associations or the species involved in the associations in a particular bay. The frequency of occurrence of flathead sole and walleye pollock was essentially equal in Kiliuda Bay but only flathead sole were found associated with northern pink shrimp. This was opposite of Two-Headed Bay where an association was found involving the less numerous walleye pollock. Twenty-seven fish species were observed in Ugak Bay as opposed to 35 in Two-Headed Bay, yet the former bay showed 5 significant associations while the latter only one.

6. Relationships of Northern Pink Shrimp and Associated Fish Species

6.1 Ugak Bay

The only significant species relationship in 1976 and 1977 was found between northern pink shrimp and yellowfin sole (Table 6). The relationship observed in 1977 was stronger than that of 1976. No significant relationships were observed between northern pink shrimp and fish species in 1978.

Table 6. Analysis of variance and biomass regression for species associated with northern pink shrimp in Ugak Bay. N is the number of stations sampled; F is the variance ratio; P is the probability of wrongfully rejecting the null hypothesis; and r is the correlation coefficient.

Species	1976				1977				1978				Combined data			
	N	F	P	r	N	F	P	r	N	F	P	r	N	F	P	r
Arrowtooth flounder	2	-	-	-	1	-	-	-	1	-	-	-	4	10.2	0.086*	0.914
Flathead sole	13	2.41	0.149	0.424	5	3.48	0.159	-0.733	8	0.63	0.457	-0.309	26	0.09	0.77	0.634
Pacific halibut	4	0.03	0.879	0.121	0	-	-	-	3	0.03	0.888	-0.175	7	1.51	0.273	-0.482
Yellowfin sole	12	3.83	0.079*	0.526	5	9.34	0.055*	0.870	7	0.67	0.449	-0.345	24	0.99	0.331	0.208
Pacific cod	2	-	-	-	1	-	-	-	1	-	-	-	4	0.01	0.928	0.072
Walleye pollock	15	3.02	0.106	0.434	4	0.94	0.436	0.564	2	-	-	-	21	0.57	0.460	0.170
Pacific sandfish	15	2.69	0.125	0.414	5	3.01	0.181	0.708	3	0.02	0.909	-0.142	23	0.26	0.615	0.111
Capelin	11	0.00	0.946	0.023	3	11.88	0.180	0.960	7	0.26	0.632	0.222	21	0.03	0.861	-0.041

*Significance level $P \leq 0.10$

The data for the years 1976-78 indicated a very strong interspecific relationship between northern pink shrimp and arrowtooth flounder, but not for Pacific cod. Low sample size suggests that the relationship involving arrowtooth flounder should be questioned. No other significant relationships were found in the combined data.

6.2 Kiliuda Bay

Pacific cod and walleye pollock were observed as having significant relationships with northern pink shrimp in 1976 (Table 7). The relationship between northern pink shrimp and Pacific cod was stronger. No significant species relationships were determined in 1977.

In 1978 arrowtooth flounder, Pacific sandfish and capelin were found related to northern pink shrimp. The relationships involving arrowtooth flounder and Pacific sandfish were very strong.

During the period 1976 through 1978, arrowtooth flounder and walleye pollock were related to northern pink shrimp. Arrowtooth flounder showed a stronger relationship with northern pink shrimp than walleye pollock.

6.3 Two-Headed Bay

Table 8 shows that in 1976, northern pink shrimp were found related to Pacific halibut and Pacific cod. These relationships were strong and that for Pacific halibut was a negative relationship. As with arrowtooth flounder in Ugak Bay, the low sample size for Pacific halibut suggests questioning of the results.

Table 7. Analysis of variance and biomass regression for species associated with northern pink shrimp in Kiliuda Bay. N is the number of stations in sample, F is the variance ratio; P is the probability of wrongfully rejecting the null hypothesis; and r is the correlation coefficient.

Species	1976				1977				1978				Combined data			
	N	F	P	r	N	F	P	r	N	F	P	r	N	F	P	r
Arrowtooth flounder	16	0.20	0.658	0.120	2	-	-	-	7	63.48	0.001*	0.963	25	14.19	0.001*	0.618
Flathead sole	24	0.27	0.607	-0.111	18	1.35	0.262	0.279	18	0.01	0.929	0.023	60	0.19	0.663	0.058
Pacific halibut	14	0.69	0.423	-0.233	5	1.40	0.322	-0.564	2	-	-	-	21	1.15	0.298	-0.239
Yellowfin sole	10	0.03	0.870	0.060	4	4.79	0.160	-0.840	10	2.52	0.151	0.489	24	0.05	0.819	0.049
Pacific cod	9	28.77	0.001*	0.897	1	-	-	-	8	>0.01	0.989	-0.006	18	0.68	0.421	0.202
Walleye pollock	39	35.27	>0.001*	0.699	20	0.03	0.862	0.042	9	1.87	0.214	-0.459	68	5.90	0.018*	0.287
Pacific sandfish	12	9.77	0.401	0.268	4	4.79	0.160	0.84	5	36.42	0.010*	0.961	21	1.90	0.184	0.302
Capelin	22	0.00	0.950	0.014	17	0.81	0.382	0.226	13	5.38	0.041*	0.573	52	0.47	0.498	0.096

*Significance level $P \leq 0.10$

Table 8. Analysis of variance and biomass regression for species associated with northern pink shrimp in Two-Headed Bay. N is the number of stations in sample; F is the variance ratio; P is the probability of wrongfully rejecting the null hypothesis; and r is the correlation coefficient.

Species	1976				1977				1978				Combined data			
	N	F	P	r	N	F	P	r	N	F	P	r	N	F	P	r
Arrowtooth flounder	14	2.23	0.161	0.396	16	0.60	0.453	0.202	18	>0.01	0.988	-0.004	48	0.26	0.610	0.076
Flathead sole	19	0.14	0.717	-0.139	26	0.46	0.503	-0.137	19	0.71	0.209	0.302	64	2.06	0.156	-0.180
Pacific halibut	4	114.27	0.009*	-0.991	10	15.06	0.005*	0.808	0	-	-	-	14	1.09	0.316	0.289
Yellowfin sole	4	8.17	0.104	0.896	14	96	>0.001*	0.943	5	14.11	0.033*	-0.908	23	53.63	>0.001*	0.848
Pacific cod	3	157.40	0.051*	0.997	6	79.22	0.001*	0.976	10	1.31	0.789	0.398	19	178.53	>0.001*	0.958
Walleye pollock	24	2.06	0.165	0.293	19	1.65	0.217	0.297	12	0.12	0.737	0.109	55	7.37	0.009*	0.350
Pacific sandfish	1	-	-	-	5	13.67	0.034*	0.906	5	0.42	0.562	0.351	11	75.77	>0.001*	0.945
Capelin	14	0.11	0.747	-0.095	5	6.57	0.083*	0.829	5	0.36	0.592	0.326	24	8.15	0.009*	0.520

*Significance level $\leq$ 0.10

During 1977, yellowfin sole and Pacific cod were found to have strong relationships with northern pink shrimp. Other weaker relationships involved Pacific sandfish, capelin and Pacific halibut.

In 1978, yellowfin sole showed a strong relationship with northern pink shrimp. Similar to Pacific halibut in 1976, this was an inverse relationship.

The combined data showed 5 significant relationships between northern pink shrimp and fish species. These species included yellowfin sole, Pacific cod, walleye pollock, Pacific sandfish and capelin. The strength of the relationship of northern pink shrimp with Pacific cod and Pacific sandfish was strong. The relationship involving walleye pollock was weak.

6.4 Alitak Bay

In 1976 a strong, inverse relationship existed between northern pink shrimp and yellowfin sole (Table 9). This may have resulted from a low sample size. A strong relationship involving Pacific halibut was observed in 1977. In 1978, a rather weak relationship was found involving flathead sole. In the combined data, weak interspecific relationships involving Pacific halibut and walleye pollock were observed.

summarizing the results for the four bays, there is no apparent connection between the number of interspecific relationships and the number of associations in a particular bay. In Ugak Bay, one species was found related to northern pink shrimp, although 5 associations were observed. In contrast to this, Kiliuda Bay had 5 associations and 5 species showing significant relationships. In Two-Headed Bay, one

Table 9. Analysis of variance and biomass regression for species associated with northern pink shrimp in Alitak Bay. N is the number of stations in sample; F is the variance ratio; P is the probability of wrongfully rejecting the null hypothesis; and r is the correlation coefficient.

Species	1976				1977				1978				Combined data			
	N	F	P	r	N	F	P	r	N	F	P	r	N	F	P	r
Arrowtooth flounder	0	-	-	-	0	-	-	-	1	-	-	-	1	-	-	-
Flathead sole	6	0.85	0.409	0.418	13	>0.01	0.973	0.011	14	3.66	0.080*	-0.483	33	1.0	0.325	0.177
Pacific halibut	3	0.90	0.517	-0.688	5	6.72	0.081*	0.832	3	0.76	0.544	-0.657	11	4.73	0.058*	0.587
Yellowfin sole	3	161.56	0.050*	-0.997	7	1.49	0.277	0.475	10	0.13	0.730	0.126	20	0.12	0.731	-0.082
Pacific cod	0	-	-	-	2	-	-	-	1	-	-	-	3	2.02	0.391	-
Walleye pollock	6	0.91	0.394	-0.431	5	1.66	0.288	0.597	2	-	-	-	13	4.71	0.053*	-0.547
Pacific sandfish	0	-	-	-	3	0.24	0.710	0.440	6	0.83	0.415	0.414	9	1.36	0.282	0.403
Capelin	2	-	-	-	7	>0.01	0.983	-0.010	11	0.22	0.648	-0.155	20	>0.01	0.952	0.014

*Significance level $P \leq 0.10$

significant association was found but 10 significant relationships were observed.

6.5 Combined Data for Four Bays

Table 10 shows that Pacific cod and walleye pollock were significantly related to northern pink shrimp during 1976. The relationship was much stronger for Pacific cod than walleye pollock.

More significant relationships were observed in 1977 than in 1976 or 1978. Pacific halibut, yellowfin sole, Pacific cod, Pacific sandfish and capelin were related to northern pink shrimp during 1977. Pacific cod had the strongest relationship.

In 1978, arrowtooth flounder was the only fish species showing a significant reltionship. This relationship was found only in 1978, but was of sufficient strength to influence the determination of relationships in the combined data. Similar influence may have been exerted by the yellowfin sole in 1977.

Data for the 1976-1978 period showed interspecific relationships between northern pink shrimp and arrowtooth flounder, yellowfin sole and Pacific cod. The relationship between northern pink shrimp and Pacific cod was slightly stronger than that of arrowtooth flounder and yellowfin sole.

6.6 Reproductive Season, October-March

In 1976, no significant relationships were found with fish species during the northern pink shrimp reproductive season (Table 11). In 1977,

Table 10. Analysis of variance and biomass regression of species associated with northern pink shrimp in Ugak, Kiliuda, Two-Headed and Alitak Bays. N is the number of stations in sample; F is the variance ratio; P is the probability of wrongfully rejecting the null hypothesis; and r is the correlation coefficient.

Species	1976				1977				1978				Combined data			
	N	F	P	r	N	F	P	r	N	F	P	r	N	F	P	r
Arrowtooth flounder	32	1.14	0.295	0.191	19	0.54	0.473	0.175	27	19.9	0.001*	0.666	78	8.19	0.010*	0.312
Flathead sole	62	0.01	0.941	0.010	62	1.26	0.267	-0.143	59	0.16	0.695	-0.052	183	0.12	0.727	-0.026
Pacific halibut	25	2.11	0.160	-0.290	20	17.9	0.001*	0.706	8	0.08	0.786	-0.115	53	0.42	0.519	0.091
Yellowfin sole	29	0.73	0.400	0.162	30	19.55	>0.001*	0.641	32	0.23	0.636	0.087	91	4.99	0.028*	0.230
Pacific cod	43	10.6	0.002*	0.844	10	27.4	0.001*	0.880	19	0.41	0.532	0.153	43	10.9	0.002*	0.453
Walleye pollock	84	4.14	0.045*	0.219	48	2.54	0.118	0.229	25	0.15	0.700	-0.081	157	1.92	0.168	0.110
Pacific sandfish	28	0.71	0.406	0.163	17	7.31	0.016*	0.572	19	0.03	0.855	-0.045	64	2.74	0.103	0.206
Capelin	49	0.56	0.458	-0.109	32	8.91	0.006*	0.479	36	0.73	0.400	0.145	117	0.38	0.540	0.057

*Significance level $P \leq 0.10$

Table 11. Analysis of variance and biomass regression for data collected during the reproductive period of northern pink shrimp (October-March). N is the number of stations sampled; F is the variance ratio; P is the probability of wrongfully rejecting the null hypothesis; and r is the correlation coefficient.

Species	1976				1977				1978				Combined data			
	N	F	P	r	N	F	P	r	N	F	P	r	N	F	P	r
Arrowtooth flounder	13	0.25	0.629	0.148	1	-	-	-	12	2.37	0.155	0.438	26	1.01	0.325	0.201
Flathead sole	22	0.13	0.726	0.079	28	1.18	0.288	0.208	24	0.13	0.717	-0.078	74	0.01	0.928	-0.011
Pacific halibut	5	0.04	0.850	0.118	7	18.40	0.008*	0.889	4	0.17	0.720	0.280	16	15.28	0.002*	0.722
Yellowfin sole	18	0.66	0.428	0.199	9	2.75	0.141	0.531	19	0.25	0.622	0.131	46	1.85	0.181	0.201
Pacific cod	3	7.30	0.226	-0.938	7	21.21	0.006*	0.900	8	0.68	0.440	-0.320	18	29.23	>0.001*	0.804
Walleye pollock	37	0.92	0.344	0.160	13	0.51	0.489	-0.211	2	-	-	-	52	0.08	0.779	-0.040
Pacific sandfish	11	1.23	0.296	0.347	8	17.32	0.006*	0.862	2	-	-	-	21	0.37	0.550	0.139
Capelin	16	0.67	0.425	-0.214	31	8.58	0.007*	0.478	17	7.67	0.014*	0.582	64	0.20	0.660	0.056

*Significance level $P \leq 0.10$

Pacific cod, Pacific sandfish, Pacific halibut and capelin were found to have significant relationships. Among the 4 related species, capelin showed the weakest relationship. In 1978, capelin was the only species showing a significant relationship.

The combined data showed that Pacific halibut and Pacific cod were significantly related to northern pink shrimp during the reproductive season. The interspecific reltionship with Pacific cod was stronger than that with Pacific halibut.

6.7 Growth Season, April-September

Table 12 shows that in 1976 the relationship between northern pink shrimp and Pacific cod was much stronger than that with walleye pollock. Pacific cod, capelin and yellowfin sole were determined to be significantly related to northern pink shrimp during the 1977 growth season. Similar to 1976, the relationship with Pacific cod was strong. The only significant relationship observed during 1978 involved arrowtooth flounder.

The combined data collected during the growth period showed that arrowtooth flounder, Pacific halibut, yellowfin sole and walleye pollock were found to have weak relationship with northern pink shrimp.

Comparisons of water temperature trends and shifts in species relationships indicate that there was no relationship between these phenomena. Sea surface temperature data (Fig. 4) from the Gulf of Alaska showed a warming trend from 1976 through 1978 while interspecific relationships varied from year to year, bay to bay, and season to season. This is not to imply that such a relationship does not exist. Water

Table 12. Analysis of variance and biomass regression for data collected during the growth period of northern pink shrimp (April-September). N is the number of stations in sample; F is the variance ratio; P is the probability of wrongfully rejecting the null hypothesis; and r is the correlation coefficient.

Species	1976				1977				1978				Combined data			
	N	F	P	r	N	F	P	r	N	F	P	r	N	F	P	r
Arrowtooth flounder	19	0.86	0.366	0.220	18	0.50	0.490	0.174	15	12.40	0.004*	0.698	52	5.88	0.019*	0.324
Flathead sole	40	0.12	0.720	-0.056	34	1.03	0.318	-0.176	35	0.22	0.641	-0.082	109	0.19	0.667	-0.042
Pacific halibut	20	1.87	0.188	-0.307	13	2.51	0.142	-0.431	4	0.61	0.516	-0.484	37	3.00	0.092*	-0.281
Yellowfin sole	11	0.00	0.993	-0.003	21	20.95	>0.001*	0.724	13	0.04	0.838	0.063	45	3.51	0.068*	0.275
Pacific cod	11	26.50	0.001*	0.864	3	71.63	0.075*	0.993	11	0.04	0.851	0.065	25	1.28	0.270	0.229
Walleye pollock	47	5.11	0.029*	0.319	35	1.03	0.318	0.174	23	0.23	0.633	0.105	105	9.12	0.003*	0.285
Pacific sandfish	17	0.05	0.822	-0.059	9	10.98	0.013*	0.782	17	0.08	0.781	-0.073	43	1.25	0.270	0.172
Capelin	33	0.00	0.775	0.052	1	-	-	-	19	0.00	0.949	-0.016	53	0.28	0.597	0.074

*Significance level $P \leq 0.10$

temperature data for the bays of Kodiak Island were limited and were not available for the time period addressed. Water temperature variations were inferred from available sea surface temperature data which precluded the use of statistical testing to judge the validity of this conclusion.

7. Estimated Predation Pressure

Table 13 summarizes the importance of shrimp in the diet of the six major predator species as found in the current literature. Shrimp biomass, expressed as percent of stomach contents by weight, ranges from 0.2% for walleye pollock in the eastern Bering Sea to 78% for adult Pacific cod in Kiliuda Bay. The percent frequency of occurrence of shrimp in stomachs ranges from 3% in yellowfin sole in Kiliuda Bay to 100% for walleye pollock in the same bay. The effect of these predators upon northern pink shrimp varies with area, time of year, and size and age of the predator. Shrimp appear to be more important in the diet of Kodiak Island predators than in the Bering Sea. Differences may be linked to the abundance of shrimp in the areas studied since low concentrations of shrimp are found in the southeast Bering Sea. The abundance of shrimp and the confining effect of the bays of Kodiak Island may increase the potential for predation. It is also suggested that shrimp are more important in the diet of adult fish than juveniles. There is no apparent trend in the seasonal importance of shrimp in the diets of these predators.

Predator biomass per unit area was estimated for the respective bays and for all the bays (Tables 14 and 15). These values indicate that

Table 13. Relative importance of shrimp in the diet of six predator species associated with northern pink shrimp.

Species	Area	Month	Length (cm)	Age	Weight (%)	Frequency (%)	Source
Flathead sole	Kodiak Shelf	February				36.7	Jewett unpublished data
	Kodiak Shelf	June-July				39.0	Jewett unpublished data
	Kiliuda Bay	May-July		Juvenile	49	18	Rogers *et al.* 1979
				Adult	80	62	
	Eastern Bering		15-50		0.8-40		
	Sea	Oct.-Nov.	30		18.4		Mito 1974
Yellowfin sole	Kodiak Shelf	February				39.1	Jewett unpublished data
	Kiliuda Bay	April-June		Adult	18	3	Rogers *et al.* 1979
	Southeast Bering						
	Sea					64-98	Skalkin 1968
Arrowtooth flounder	Eastern Bering		20-65		0.7-15		
	Sea	Oct. Nov.	38		6.4		Mito 1974
	Gulf of Alaska				24		Smith *et al.* 1976
Pacific halibut	Southeast Bering						
	Sea		1-8			50	Best 1976
	Bering Sea		5-30			78	Novikov 1968
			30-60			33	
			60-90			13	
Pacific cod	Kodiak Shelf	June-July				28.0	Jewett unpublished data
	Izhut Bay	May				88.2	
	Kiliuda Bay	August				100	
	Kodiak Shelf	February				22.2	
	Kodiak Island	June-Aug.	73-92			18-42	Jewett 1978
		June-July	58-72			25-35	
		June-July	38-52			15-32	
	Kiliuda Bay	June-July		Adult	78	70	Rogers *et al.* 1979
				Juvenile	42	52	
	Eastern Bering	Oct.-Nov.	25-80		2.4-22		Mito 1974
	Sea		46		10.0		
Walleye pollock	Eastern Bering	Oct.-Nov.	20-70		0.2-6.8		
	Sea		37		2.8		
			25-80		2-8		Takahashi and Yamaguchi 1972
	Gulf of Alaska	Summer	36-50			8	Smith *et al.* 1976
	Kiliuda Bay	August				100	Jewett unpublished data

Table 14. Biomass per unit area (kg/km^2) for predator species associated with northern pink shrimp for 1976, 1977 and 1978.

Species	1976			1977			1978		
	N	Range	Mean	N	Range	Mean	N	Range	Mean
Ugak Bay									
Arrowtooth flounder	2	65.8- 289.7	177.8	1		276.5	1		2,277.2
Flathead sole	13	39.5- 1,185.1	539.4	4	65.8- 1,303.6	658.4	8	184.3- 4,121.4	1,578.4
Pacific halibut	4	92.1- 553	396.6	0	-	-	3	13.1- 197.5	96.6
Yellowfin sole	12	105.3- 5,756.3	1,025.0	5	289.7- 2,001.4	1,170.5	7	223.8- 3,423.5	1,427.8
Pacific cod	2	79.0- 223.8	151.4	1		65.8	1		131.7
Walleye pollock	15	52.6-45,916.5	3,722.8	4	52.7- 526.7	246.8	2	79.0- 882.2	480.6
Kiliuda Bay									
Arrowtooth flounder	16	52.6- 1,817.1	595.8	2	724.2- 2,093.6	1,408.9	7	131.7- 3,568.3	848.8
Flathead sole	24	79.0- 5,135.2	1,763.9	18	71.4- 3,212.8	914.6	18	65.8- 3,239.1	1,360.2
Pacific halibut	14	13.1- 3,160.1	312.5	5	39.5- 1,448.4	429.2	2	65.8	65.8
Yellowfin sole	10	92.1- 1,092.9	809.8	4	26.3- 934.9	596.5	10	92.1- 2,488.6	1,159.4
Pacific cod	9	65.8- 4,898.2	968.5	1		39.5	9	263.3-19,553.4	5,322.9
Walleye pollock	39	52.6-10,533.8	2,363.8	20	171.2- 6,939.2	2,848.9	9	939.2-15,050.2	6,013.4
Two-Headed Bay									
Arrowtooth flounder	14	52.6- 1,448.4	169.3	16	39.5- 6,610	929.1	18	26.3- 2,462.3	892.5
Flathead sole	19	105.3- 3,265.5	652.1	16	184.3- 3,041.6	996.7	19	65.8- 8,308.5	2,299.4
Pacific halibut	4	26.3- 658.4	207.4	10	26.3- 2,014.6	351.6	0	-	-
Yellowfin sole	4	131.7- 1,514.2	516.8	14	39.5- 3,515.7	712.8	5	15.8- 8,295.5	447.7
Pacific cod	3	263.3- 2,027.8	1,009.5	6	52.6-53,709.3	8,442.1	10	26.3- 4,503.2	1,527.4
Walleye pollock	24	118.5-18,855.5	3,090.5	19	79.0- 2,488.6	803.9	12	65.8- 4,332	1,509.8
Alitak Bay									
Arrowtooth flounder	0	-	-	0	-	-	1		79.0
Flathead sole	6	131.7- 316	223.8	13	105.3- 961.2	336.3	14	15.8- 1,514.2	796.1
Pacific halibut	3	79.0- 1,053.4	596.9	5	131.7- 7,633.5	895.4	3	65.8- 438.9	234.1
Yellowfin sole	3	408.2- 882.2	488.1	7	513.5- 1,540.6	912.3	10	26.3- 4,397.9	1,813.6
Pacific cod	0	-	-	2	184.3- 618.9	401.6	1		197.5
Walleye pollock	6	921.7-12,759.1	3,776.8	5	210.7- 1,817.1	813.7	2	961.2-50,180.5	25,570

Table 15. Cumulative biomass per unit area (kg/km^2) for predator species associated with northern pink shrimp in Ugak, Kiliuda, Two-headed and Alitak Bays for 1976, 1977 and 1978.

Year	N	Range	Mean
1976	233	13.1-18,855.5	1,569.0
1977	180	26.3-53,709.4	1,289.2
1978	232	13.1-19.553.4	2,047.6

predator biomass in the bays examined decreased slightly from 1976 to 1977 and then increased in 1978. Table 16 shows the estimated predation pressure for each predator species. The estimated values of predation pressure indicate that flathead sole and Pacific cod were important predators of shrimp during the study period. It is noteworthy that predation of shrimp by walleye pollock increased drastically in 1978. Shrimp biomass removed by arrowtooth flounder and yellowfin sole remained relatively stable from year to year.

Table 17 shows the estimated total predation pressure in the areas commercially exploited during the respective fishing season. Predation pressure in 1977 is estimated to be twice that found in 1976 or 1978. Biomass of northern pink shrimp removed by predation in 1976 was estimated to be 84% of the commercial catch of the year. Increased predation and decreased catch inflated this value in 1977 and 1978 when predation removed 2.65 and 4.82 times more shrimp biomass than the respective commercial harvest.

DISCUSSION

The family Pandalidae has supplied the basis for a major shrimp fishery in the waters of Kodiak Island for approximately 20 years. The management plan for this fishery, described in the Alaska Commercial Shellfish Regulations, designates the individual bays as statistical areas. The resulting separation of management strategies has arbitrarily established a fishery within each major bay of the island. Also, northern pink shrimp stocks in the bays of this island are considered separate

Table 16. Estimates of predation pressure expressed as shrimp biomass ($kg/[km^2 \cdot day]$) removed.

Species	Year 1976	1977	1978
Arrowtooth flounder	1.0	2.2	0.9
Flathead sole	16.6	14.2	12.0
Yellowfin sole	5.2	5.9	6.1
Pacific cod	10.4	48.5	9.1
Walleye pollock	3.9	1.9	11.4
Total	37.1	72.7	39.5

Table 17. Commercial catch in actively fished areas.

Season	Area	Commercial Catch		
		kg	kg/km^2	kg/(km^2·day)
1976-1977	Kiliuda - Two-Headed-Alitak	10.6×10^6	16.2×10^3	44.4
1977-1978	Kiliuda - Two-Headed-Alitak	6.5×10^6	10.0×10^3	27.4
1978-1979	Two-Headed - Alitak	1.5×10^6	3.0×10^3	8.2

stocks by the ADF&G (McCray pers. comm.). The bays of interest were once the four principal fishing areas in the Kodiak shrimp fishery. Recent declines in catch in these bays have shifted the base of the fishery to other bays.

Presently, it is impossible to verify the existence of separate stocks based on biological characteristics of northern pink shrimp. Management strategies and the physical nature of these bays is such that the data were collected under the premise of separate stocks. The validity of separate shrimp stocks is not argued in this study, but rather, the study was done accepting the hypothesis that separate shrimp stocks exist in the bays.

The bays examined in this thesis were the major fishing areas in the Kodiak shrimp fishery. These bays, Ugak, Kiliuda, Two-Headed and Alitak Bays, are found along the eastern and southern coast of Kodiak Island extending over a distance of approximately 161 km. The distance separating the mouths of the bays ranges from approximately 18 km between Ugak and Kiliuda Bays to 53 km from Two-Headed to Alitak Bay. The only interior connection of the bays is a narrow, 3-m-deep-strait between Kiliuda and Two-Headed Bays.

Seasonal distribution of northern pink shrimp populations has been described in detail by Appolonio and Dunton (1969) in the Gulf of Maine. From late spring to early fall, inshore populations are predominated by 0-group and 1-group shrimp. In late November, the 1-group begins moving into deeper, offshore waters and has emigrated completely from the inshore waters by early spring. During the third winter, these males are generally found in deep water at distances greater than 16 km offshore. Male maturation is completed in these waters and during the winter this group is characterized by an increasing percent of transitionals. In the fall, ovigerous females migrate to shallower, inshore waters and remain in there until the larvae are released in the spring. The extent of migration in the Gulf of Maine is approximately 56 km offshore and to depths of approximately 200 m.

At present, the extent of seasonal distribution of northern pink shrimp in the bays of Kodiak Island is uncertain. Dodimead and Hollister (1962) indicate that Alaska Stream enters the bays along the east coast of Kodiak Island. It is possible that seasonal migration of northern pink shrimp into areas affected by this current could result in the transport of shrimp from bay to bay. A migration of approximately 56 km from the farthest inland point of Alitak Bay would place shrimp at the mouth of this bay or beyond. Ugak, Kiliuda, and Two-Headed bays are shorter than Alitak Bay, so that migration similar to that found in the Gulf of Maine could remove these shrimp from the boundaries of these bays. Research on the effect of currents within and without these bays is needed.

Another possibility of movement of shrimp out of the bays is long-distance transport by the Alaska Stream. The extent of this movement would depend on the velocity and meanders of the current. Laboratory observations show that northern pink shrimp align themselves parallel to the current and swim with the current (Ippolito unpublished data). It is not known if these shrimp are strong enough swimmers to overcome the force of this current. The relationship between migration, current systems and interspecific relationships should be studied further.

In the aquatic environment, crustaceans are nekto-benthic organisms which act as intermediaries in the transfer of energy and material from benthic to pelagic organisms (Momot *et al.* 1978). The magnitude of commercial catch showed that northern pink shrimp were well established in the bays of this island. The gullies which serve as the principal fishing areas may act as settling basins for organic material settling from the water column. Haynes and Wigley (1969) found that abundance of northern pink shrimp is correlated with the content of organic carbon in the sediment. As suggested by Rice *et al.* (1980), northern pink shrimp are a key in the transfer of organic carbon from the sediment to benthic and pelagic predators. It is possible that northern pink shrimp concentrations change trophic relations in specific areas. Changes in shrimp abundance could affect the overall production of the ecosystem. Predator-prey relationships are a mechanism in the transfer of energy and matter.

The interspecific relationships observed in Ugak, Kiliuda, Two-Headed and Alitak Bays are dynamic phenomena with varying impact upon the northern pink shrimp population. The predators found significantly related to northern pink shrimp are arrowtooth flounder, flathead sole, halibut, yellowfin sole, Pacific cod and walleye pollock. Pacific cod are demersal and pelagic feeders and walleye pollock are pelagic feeders. Barr (1970) showed that male northern pink shrimp migrate vertically to a greater extent than females. It is likely that vertical migration increases the exposure of portions of the northern pink shrimp population to predators such as Pacific cod, walleye pollock and other demersal and pelagic species.

Filter feeding Pacific sandfish and capelin are related to northern pink shrimp, but are not predators of adult shrimp. These species are perhaps more important to larval pink shrimp through competition for food and predation. It is known that larval northern pink shrimp (zoeae Stage 1) require a prey density of 80 organisms per liter to elicit a successful feeding response (Paul *et al.* 1978). Zooplankton density in the bays could be affected by planktonic filter feeders such as Pacific sandfish, capelin, eulachon, smelt and the larval forms of other fish species. In addition to competing with larval northern pink shrimp for available zooplankton, these fish species may prey upon the planktonic shrimp larvae. Predation affects northern pink shrimp throughout its life, although the specific predator may change as the individuals grow and distributional patterns change. No trends were observed in species relationships during the either reproductive or growth period of northern pink shrimp. Relationships found during the reproductive period were fewer and stronger than those found during the growth period. It is presumable that the reproductive period of northern pink shrimp and many predatory fish overlap. Incubation of northern pink shrimp egg occurs while the eggs are being carried by the female. This combination of predation pressure and fishing pressure during the reproductive period could result in reduction of the reproductive and recruitment potential of the population. Fishing tends to selectly remove females from the population, and in doing so, also removes possible recruits.

Protandric hermaphroditism may provide a buffer for the northern pink shrimp population allowing it to respond to the impact of exploitation. Protandric hermaphroditism provides each individual with the reproductive potential which enables the population to exploit favorable environmental conditions (Appolonio and Dunton 1969). In this way, the reproductive capacity of the population is efficiently utilized. Controlled fishing pressure could remove shrimp in excess of reproductive value and not destroy the reproductive potential of the population. It is established that production in the Gulf of Maine is related to water temperature (Appolonio and Dunton 1969; Dow 1979); the lower the water temperature, the earlier the egg production takes place. In waters of approximately 8°C spawning occurs in October and November, while in water around 1.5°C, spawning takes place in August (Butler 1971). Stickney and Perkins (1978) suggest that egg development is accelerated and larval release begins earlier in warmer waters. It is possible that increased water temperatures decrease the length of the ovigerous period and hence reduce the time period in which females aggregate. The resulting earlier dispersal of females may reduce exposure of the females to predators.

The formula utilized to evaluate predation pressure in this study is a modification of Bajkov's formula for daily food consumption (Bajkov 1935). The formula provides a simple means of estimating prey biomass using data on predator biomass. However, this formula lacks information on digestive rates of the predator species. An overall feeding rate, taken from work on North Sea cod (Daan 1973) was assigned to each predator, increasing the speculative nature of the results. Berg (1979) reviewed the methods utilized for the investigation of fish stomach contents. He concluded that weight percentage is an appropriate measure of the importance of a prey species in the diet of a predator. Modification of feeding studies to include percentage of stomach content weight would aid in the future use of this formula. Problems to be examined in future feeding studies include the definition of fullness of the digestive tract and comparison of food availability in nature and food types used in the laboratory. Additionally, laboratory studies are conducted under conditions of limited prey selection and limited predator mobility.

As previously described, fifty-one fish species occurred in Ugak, Kiliuda, Two-Headed and Alitak Bays. Twenty-five of these species are documented shrimp predators (Hart 1973; Jewett 1978 and Rogers *et al.* 1979). The cumulative predation pressure of these five predators is great in relation to the effect of commercial fishing, and fishing appears negligible in comparison to total predation.

The decline of the Kodiak Island shrimp fishery cannot be assumed to be the result of a single environmental factor, but rather, the net result of a number of biotic and abiotic factors including interspecific associations and relationships involving predation and competition, predation and fishing pressure, water temperature regimes, and the current patterns found in the ecosystems.

Recently, growth of Alaskan fisheries has included expansion of the bottom fishery, concentrating on under-utilized flatfish species and walleye pollock, most of which are predators of northern pink shrimp. Future study of predator-prey relationships should include more intensive seasonal definition of changes in populations of predators and prey. Sampling should include enumeration of the individuals of a species and determination of year class structure of the population. Feeding studies need to be refined so that data usuable for the determination of predation pressure are collected.

SUMMARY

1. Catch data were used to analyze interspecific relationships involving northern pink shrimp, *Pandalus borealis* Krøyer, in Ugak, Kiliuda, Two-Headed and Alitak Bays of Kodiak Island. A total of 346 stations were occupied, 137 in 1976, 100 in 1977 and 109 in 1978. Frequency of occurrence, testing of association, and analysis of variance and regression of species biomass were used to examine interspecific relationships. The combination of association testing and analysis of variance of biomass provides a means of judging the similarity or dissimilarity of changes in the biomass of co-occurring species.

2. The four bays examined in this study vary in size, depth, shape, orientation and other factors which affect the physical oceanography of these bays. The length of the bays ranges from Alitak Bay, the largest, at 18 km to Ugak Bay, the smallest, at 10 km. Sea surface temperature in these bays ranges from 2.2 to 6.1°C from December through March and 10.8 to 12.4°C in August and September. Bottom temperatures range from 2.6 to 6.0°C from December to March and 2.0 to 9.6°C from May to September.

3. Ten shrimp species and 51 fish species were observed in these bays from 1976 to 1978. Twenty-five of these species have been found to be

predators of shrimp. Fourteen fish species were found in the top ten ranks by frequency of occurrence. Association testing showed 8 species were associated with northern pink shrimp. There was no apparent relationship between frequency of occurrence associations or interspecific relationship. Species found related to northern pink shrimp were the predators: arrowtooth flounder, flathead sole, Pacific halibut, yellowfin sole, Pacific cod and walleye pollock, and the filter feeders capelin and Pacific sandfish. Filter feeders may be an important factor in the survival of larval shrimp. Species such as capelin, Pacific sandfish, herring, eulachon and the juvenile forms of other fish species may compete with shrimp larvae for food or may prey upon the larvae.

Species relationships and the strength of these relationships varied with species, year, season and bay. Yearly differrences may be the result of changes in the age structure of the respective populations. Seasonal distributions are different during the reproductive period of this shrimp (October-March) than during the growth period (April-September). The reproductive period of northern pink shrimp overlaps the reproductive period of many co-occurring fish species. Seasonal changes in species relationships were considered to be the result of differing distribution patterns of shrimp and fish species.

4. Mean sea surface temperature, measured in the Gulf of Alaska, indicates a warming trend has occurred in the Gulf from 1976 to 1978. There is no apparent relationship between water temperature variation and changes in interspecific relationships.

5. Water temperature is a factor affecting aquatic production (Dow 1979). Seasonal water temperature fluctuations in the bays of Kodiak Island appear to be similar to fluctuations observed in the Gulf of Alaska. It was assumed that the warming trend apparent in the Gulf had also taken place Ugak, Kiliuda, Two-Headed and Alitak Bays. If increased water temperature was the driving force in the recent declines in the Kodiak shrimp fishery, declines in commercial catches in these bays should have occurred at approximately the same time. Commercial catch data showed this not to be the case.

6. Shrimp in the diet of predators, expressed as percent weight of stomach contents, varied with predator, size and age, and area studied. A formula is proposed for the evaluation of predation pressure. The proposed formula uses estimated predator biomass, the importance of a prey species in the diet of the predator and feeding rates to calculate the biomass of prey removed by a predator. Estimated biomass of the predators related to northern pink shrimp was 1,569 kg/km^2 in 1976, 1,289 kg/km^2 in 1977 and 2,048 kg/km^2 in 1978. Predation pressure increased from 1976 to 1977 and then decreased in 1978.

7. It is considered that northern pink shrimp serve an important role in the overall production of an ecosystem. This shrimp acts as an intermediary in the transfer of energy and material from the benthos to pelagic and demersal predator species. Included in these species are walleye pollock and flatfish which may supply the base for a previously undeveloped fishery in this area. Interspecific relationships and their effect within the ecosystem require additional study. Modification of sampling and

analytical techniques will allow the incorporation of this information in the formulation of future management strategies in the shrimp fishery.

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